International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 4, Issue 1, Feb 2014, 125-134

EXPERIMENTAL ANALYSIS OF RENEWABLE ENERGY AS SOLAR AIR HEATER WITH ARTIFICIAL ROUGHNESS

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ABSTRACT

The sun's energy is really powerful, renewable and it is free. Performance analysis of solar air heater duct provided with artificial roughness in the form of rhombus shape geometry has been reported in the present thesis.

The result in this paper shows that the efficiency of solar air heater with artificial roughness is 34.67% where as, the efficiency of solar air heater with plane plate is 25%. The increase in relative efficiency of roughened plate with respect to plane plate is 38.68%.

Hence, artificially roughened solar air heater performs better than the smooth ones under the same operating conditions.

KEYWORDS: Renewable Energy, Solar Air Heater, Artificial Roughness, Solar Energy

INTRODUCTION

Since industrial revolution and coming of machine era there have always been needs of energy. With every passing by day the number of machine is increasing and so is need of power.

There is an urgent need for renewable energy sources. The renewable energy industry has experienced dramatic changes over the few years. Deregulation of the electricity market failed to solve the industries problems. Also unanticipated increase in localized electricity demands and slower than expected growth in generating capacity have resulted in an urgent need or alternative energy sources, particularly those that are environmentally sound. Solar air heater has low efficiency because of low convective heat transfer coefficient between the air and absorber plate resulting in high thermal losses to environment. Flat-plate solar collectors are being for thermal conversion to raise the temperature of fluid flowing through the collector. Conversion of solar radiations to thermal energy is mainly due to hear transfer coefficient between absorber plate and the fluid flowing the collector. Several designs of solar air heater have been developed over the years in order to improve their performance. However, the efficiency of solar air collectors is low because of the low value of the convective heat transfer coefficient between the absorber plate and the air, leading to high absorber plate temperature and greater heat losses to surroundings. Close (1963) discussed solar air heaters for low and moderate temperature applications. It has been found that the main thermal resistance to the heat transfer is due to the formation of a laminar sub-layer on the heat transferring surface, which can be broken by providing artificial roughness on the heat transferring surface. The artificial roughness has been used extensively for the enhancement of forced convective heat transfer, which further requires flow at heat transferring surface to be turbulent.

History of Solar Energy

Sun is thought to be the ultimate source of all energy available on the earth. The ancient people know well the importance of sun, and worshipped the sun as a God. Many sermons and hymns are written in praise of sun in different religious books like Vedas and Upanishads. Many big temples are devoted to the 'Sun God' and many festivals are observed in reverence. But while on one side the sun was being worshipped as God, the scientists have all along been keen to harness this resource for the good of humanity.

Archimedes in 214B.C. used solar energy as a weapon of war, reducing the Roman fleet to ashes utilizing solar energy through mirrors called "Burning Glass". Salmon, de Cause French, constructed a solar engine for pumping water in 1615, which worked on the principle of air expanded by the sun's heat. M.A. Lavoisier of France constructed a solar furnace and melted materials like platinum at a temperature of about 3600°F in 1827. Cooking vegetable and stewing meat was also reported in 1837 by Herochel in a wooden solar stove. In India, the first solar steam engine of 2.5 hp. was made 1876 at Bombay by W. Adams. A French scientist could operate his printing press with a solar engine in 1880.A huge solar motor was built at South Pasadena, California in 1901 by A.G. Enesco. In 1905 another solar engine of 20 hp was successfully tested in California. The Eastern Sun Power Co. Ltd. Built a solar power plant of 100 hp at Meade, Egypt. In the wake of energy crisis, considerable research effort has now been directed towards harnessing these resources.

TEST APPARATUS AND PROCEDURE

Solar air heater was modified to get a comparative result between plane sheet and roughened sheet. One side plane absorber sheet was fixed, which was made of G.I sheet and another side roughen absorber plate was placed. Roughen absorber plate was prepared by welding of rhombus shaped plate on G.I. sheet on one side. Four different size of rhombus (having sides 1", 1.25", 1.5", 2.0" respectively) was attached on different plate to get different roughness on roughened plate. All were assembled to form the parts the test rig as shown in figure

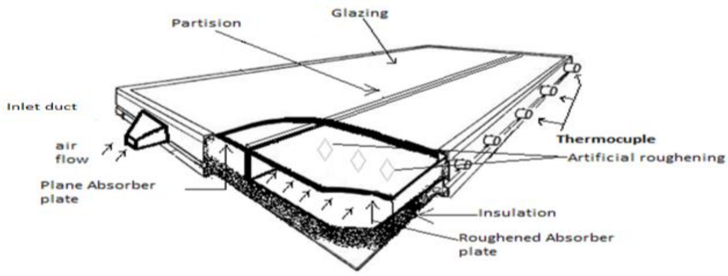


Figure 1: Test Apparatus

For temperature measurement six J type thermocouples at regular interval were installed on both side of the solar air heater. Also for flow rate measurement U tube manometer and orifice meter were attached to air feed pipe.

After the installation of all the peripherals, experiment was performed in following steps:-

- Atmospheric temperature ($T_{amb.}$) was noted.
- Blower was operated till the water column in U tube manometer was stable to get a steady flow rate.
- Difference in water column on U tube manometer was noted.
- Temperatures of both sides of six thermocouple were noted from temperature indicator.
- Reading from milli-volt meter was taken, which was connected to Pyranometer, to get solar intensity.

Above procedure was repeated for different air flow rates as well as different plates having different roughness

Technical Specification

Dimension of plywood box	:-	1.405cm x 0.645cm x 0.0225 m
Thickness of plywood used	:-	12.7mm
Base insulation used	:-	saw dust (2 .5 cm thick)
Absorber plate	:-	1.4m x 0.32m
Thickness of absorber plate	:-	18 gauge
Thickness of glass	:-	3 mm
Specification of blower	:-	0.5 HP
Thermocouple	:-	j type (iron –constantan)
		-30˚C to -250˚C
D.T.I.	:-	j type six channel,
		Servotronics (0˚C to 400˚C)
Orifice meter diameter	:-	0.8 cm
U tube Manometer	:-	95cm, 1.27cm
Length of side of rhombus used	:-	1 inch, 1.25 inch, 1.5 inch, 2 inch

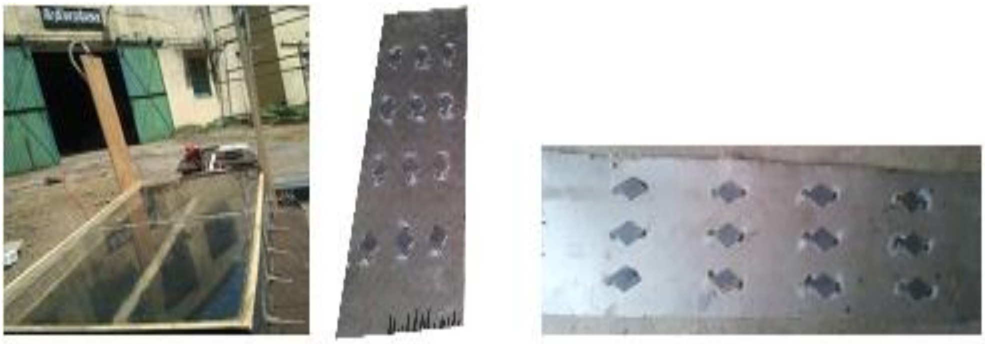


Figure 2: Experimental Apparatus

Sample Calculations

Diameter of pipe =2.54 cm =0.0254 m

Diameter of orifice = 0.8cm =0.008 m

Area of pipe (a_1) =$\frac{\pi}{4}d^2$Area of orifice (a_0) = $\frac{\pi}{4}d^2$

a_1 =5.067×10^{-4} m^2

a_0 =5.026×10^{-5} m^2 X = 31 cm = 0.31 m

h = x [$\frac{S_w}{S_a}$ – 1] = 0.31[$\frac{1}{0.0012}$ - 1] =258.023 m

Discharge of air (Q) = $\frac{C_d \times a_1 \times a_0 \sqrt{2 \times g \times h}}{\sqrt{(a_1)^2-(a_0)^2}}$

Q = $\frac{0.64 \times 5.067 \times 10^{-4} \times 5.026 \times 10^{-5} \sqrt{2 \times 9.81 \times 258.023}}{\sqrt{(5.067 \times 10^{-4})^2-(5.026 \times 10^{-5})^2}} = 2.299 \times 10^{-3}$ m^3/s

Mass flow rate of air ($\dot{m}_a$) = $\rho \times Q$

$\dot{m}_a = 1.2 \times 2.299 \times 10^{-3}$ kg/s

= 2.75×10^{-3}kg/s

Efficiency of rough plate $(\eta)_{rough} = \frac{\dot{m}_a \times C_p (T_o - T_i)}{I \times A_c}$

$= \frac{2.75 \times 10^{-3} \times 1.005 \times 10^{3} (77.17-44)}{721.1 \times 0.45} \times 100$ = 28.25%

Efficiency of plane plate $(\eta)_{plane} = \frac{2.75 \times 10^{-3} \times 1.005 \times 10^{3} (68.67-44)}{721.1 \times 0.45} \times 100$ =21.01%

Increase in efficiency = $\frac{28.25-21.01}{21.01} \times 100$ =34.46%

$(\eta)_{rough} = \frac{3.67 \times 10^{-3} \times 1.005 \times 10^{3} (74.5-44)}{721.1 \times 0.45} \times 100$ =34.67%

$(\eta)_{plane} = \frac{3.67 \times 10^{-3} \times 1.005 \times 10^{3} (66-44)}{721.1 \times 0.45} \times 100$ =25%

Increase in efficiency = $\frac{34.67-25}{25} \times 100$ = 38.68%

Where,

X = pressure difference of water

h = pressure difference of air

S_w = Specific gravity of water

S_g = Specific gravity of air

C_d = Co-efficient of discharge =0.64

I = Solar intensity (W/m^2)

A_c = area of collector

C_p = Specific heat of air =1.005 kJ/kg-K

T_o = Outlet temperature of air(°C)

T_i = Inlet temperature of air(°C)

RESULTS

From the observation table, efficiency was calculated and tabulated. From this efficiency graphs were generated and comparison was done to get the result.

Table 1

Time	Efficiency (in %) Comparison of Plane and Rough Absorber Plate at 0.00275 kg/s Mass Flow Rate							
	Plane Plate	Rough Plate Length of Side of Rhombus = 1”	Plane Plate	Rough Plate Length of Side of Rhombus = 1.25”	Plane Plate	Rough Plate Length of Side of Rhombus = 1.5”	Plane Plate	Rough Plate Length of Side of Rhombus = 2”
10.00	6.16	12.31	6.44	14.72	8.89	18.37	8.80	19.91
11.00	7.39	13.64	8.13	14.51	9.87	19.02	9.84	20.44
12.00	8.09	13.85	9.26	15.47	10.06	19.79	11.45	21.36
13.00	15.11	20.39	18.13	23.77	17.72	23.83	17.48	25.25
14.00	14.42	20.95	18.08	22.80	18.33	23.92	21.01	28.25
15.00	14.60	21.25	14.88	21.54	14.00	20.38	17.56	23.36
16.00	10.37	18.85	10.15	19.11	9.98	19.10	7.34	16.20

Table 2

Time	Efficiency (in %) Comparison of Plane and Rough Absorber Plate at 0.00305 kg/s Mass Flow Rate							
	Plane Plate	Rough Plate Length of Side of Rhombus = 1”	Plane Plate	Rough Plate Length of Side of Rhombus = 1.25”	Plane Plate	Rough Plate Length of Side of Rhombus = 1.5”	Plane Plate	Rough Plate Length of Side of Rhombus = 2”
10.00	4.43	12.42	6.33	15.10	8.23	18.90	8.42	20.72
11.00	5.57	12.93	7.95	15.20	9.11	19.44	9.86	21.63
12.00	6.72	13.28	9.59	16.65	9.64	20.81	11.71	22.15
13.00	15.93	21.47	19.11	25.38	18.69	25.94	18.39	27.17
14.00	17.84	23.38	19.60	24.84	19.85	25.89	22.19	30.22
15.00	15.47	22.86	15.98	23.54	14.83	21.74	18.78	24.52
16.00	10.66	20.06	10.50	20.63	10.49	20.39	7.38	17.22

Table 3

Time	Efficiency (in %) Comparison of Plane and Rough Absorber Plate at 0.00328 kg/s Mass Flow Rate							
	Plane Plate	Rough Plate Length of Side of Rhombus = 1”	Plane plate	Rough Plate Length of Side of Rhombus = 1.25”	Plane Plate	Rough Plate Length of Side of Rhombus = 1.5”	Plane Plate	Rough Plate Length of Side of Rhombus = 2”
10.00	4.67	13.57	5.70	15.37	7.35	17.47	6.79	19.36
11.00	6.20	14.55	7.79	16.92	8.35	18.56	10.16	21.00
12.00	7.55	15.14	8.87	17.18	12.19	20.74	11.40	21.82
13.00	15.92	22.04	19.67	26.40	19.24	26.86	19.06	28.33
14.00	18.69	24.81	20.28	26.07	20.67	26.65	23.19	31.99
15.00	16.25	23.60	16.63	24.58	15.39	22.45	19.63	26.37
16.00	10.79	20.67	10.49	21.58	10.65	21.52	7.32	17.91

Table 4

Time	Efficiency (in %) Comparison of Plane and Rough Absorber Plate at 0.00353 kg/s Mass Flow Rate							
	Plane Plate	Rough Plate Length of Side of Rhombus = 1"	Plane Plate	Rough Plate Length of Side of Rhombus = 1.25"	Plane Plate	Rough Plate Length of Side of Rhombus = 1.5"	Plane Plate	Rough Plate Length of Side of Rhombus = 2"
10.00	5.63	14.06	5.20	15.83	6.79	18.90	7.64	19.52
11.00	6.22	15.20	7.37	16.17	7.60	19.87	11.42	23.58
12.00	7.77	18.22	8.76	18.11	9.50	20.70	12.69	24.54
13.00	17.31	23.34	20.40	27.84	20.14	27.98	19.02	28.91
14.00	19.41	25.99	23.38	27.36	21.32	27.94	24.41	34.07
15.00	16.45	24.58	16.91	25.46	15.57	23.57	20.13	26.77
16.00	10.64	21.04	10.42	22.15	10.56	22.26	7.45	18.17

Table 5

Time	Efficiency (in %) Comparison of Plane and Rough Absorber Plate at 0.00367 kg/s Mass Flow Rate							
	Plane Plate	Rough Plate Length of Side of Rhombus = 1"	Plane Plate	Rough Plate Length of Side of Rhombus = 1.25"	Plane Plate	Rough Plate Length of Side of Rhombus = 1.5"	Plane Plate	Rough Plate Length of Side of Rhombus = 2"
10.00	7.38	15.38	4.67	15.22	8.35	21.27	9.48	22.77
11.00	9.81	17.25	6.80	16.18	9.59	21.98	11.37	23.50
12.00	9.97	18.89	8.29	18.01	12.77	22.01	11.83	24.70
13.00	17.22	23.48	20.22	27.96	19.98	28.51	19.53	30.11
14.00	19.43	26.29	21.42	27.73	21.59	28.09	25.00	34.66
15.00	16.46	24.68	16.96	25.65	15.57	23.45	20.30	27.62
16.00	10.06	21.12	10.16	22.12	10.05	22.44	9.56	20.94

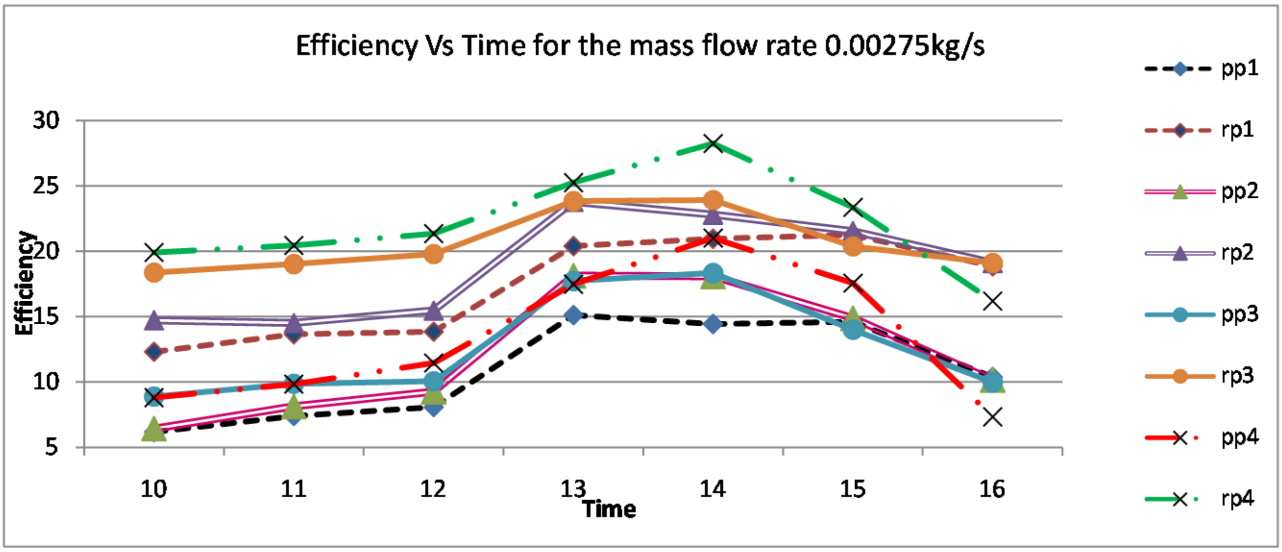
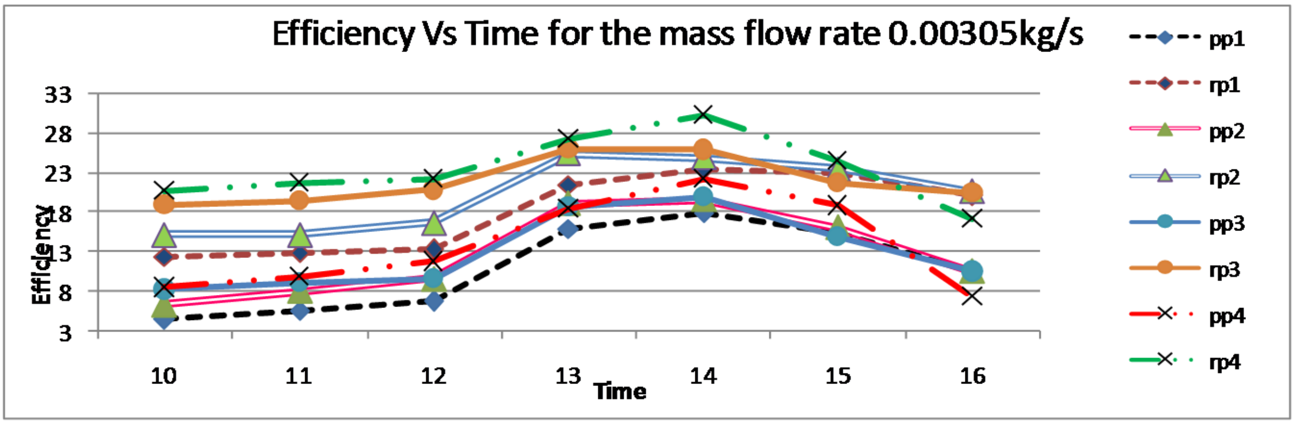


Figure 3



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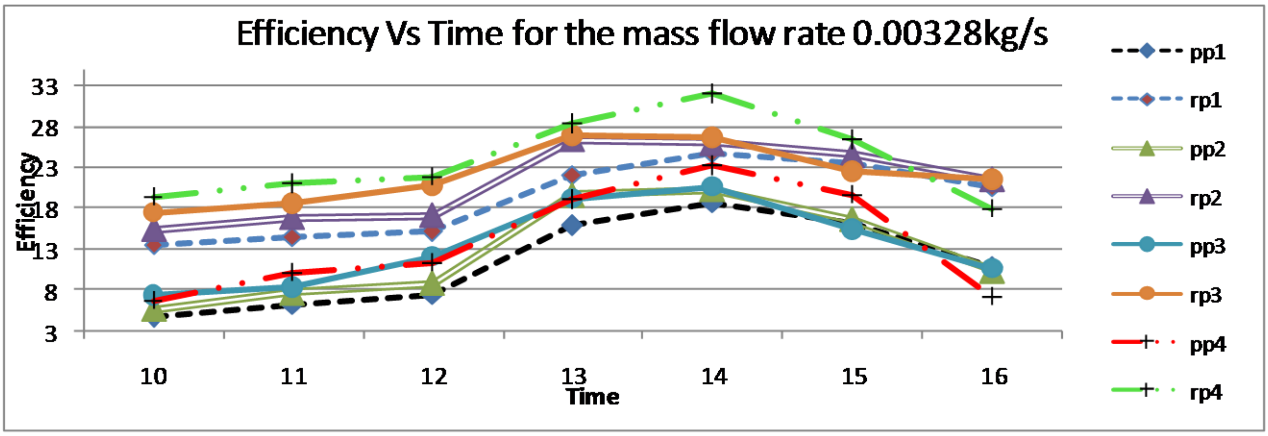

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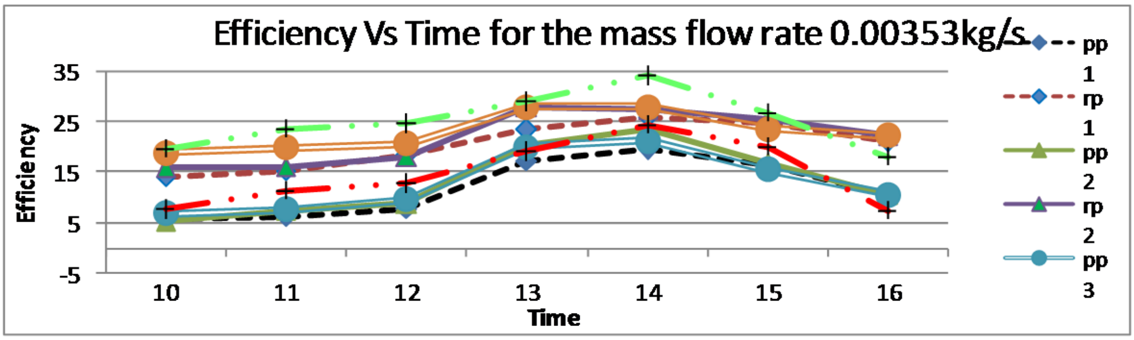

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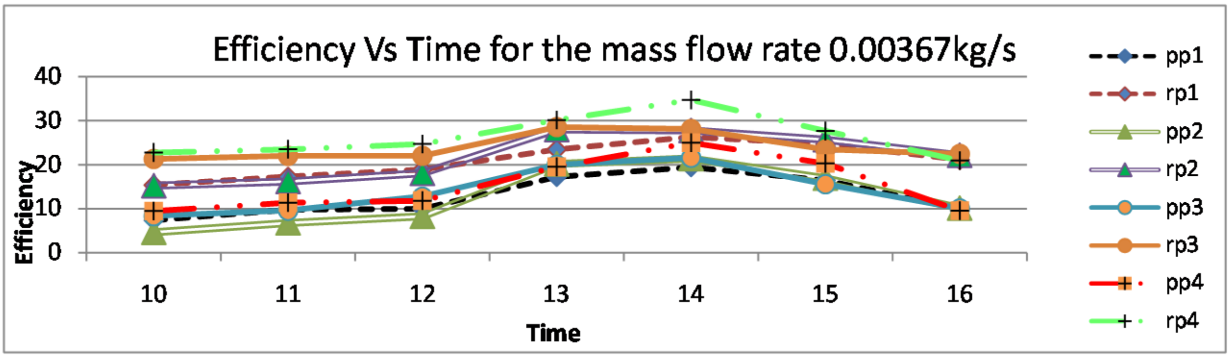
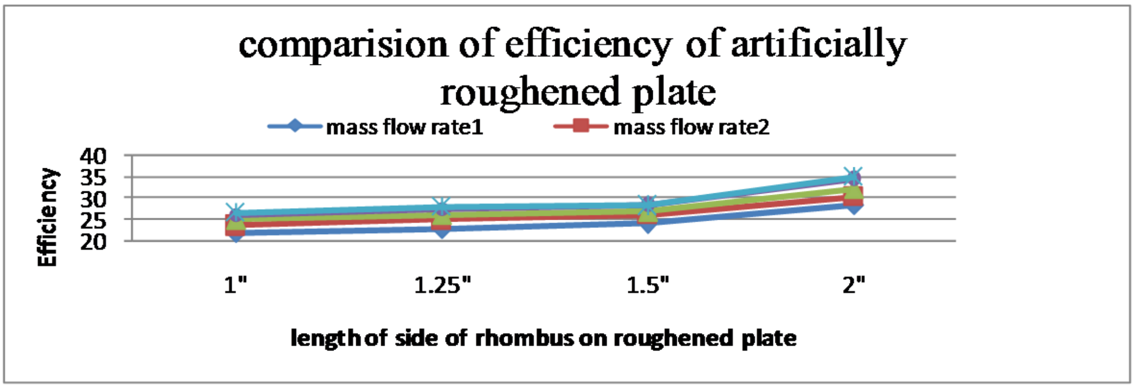


Figure 7



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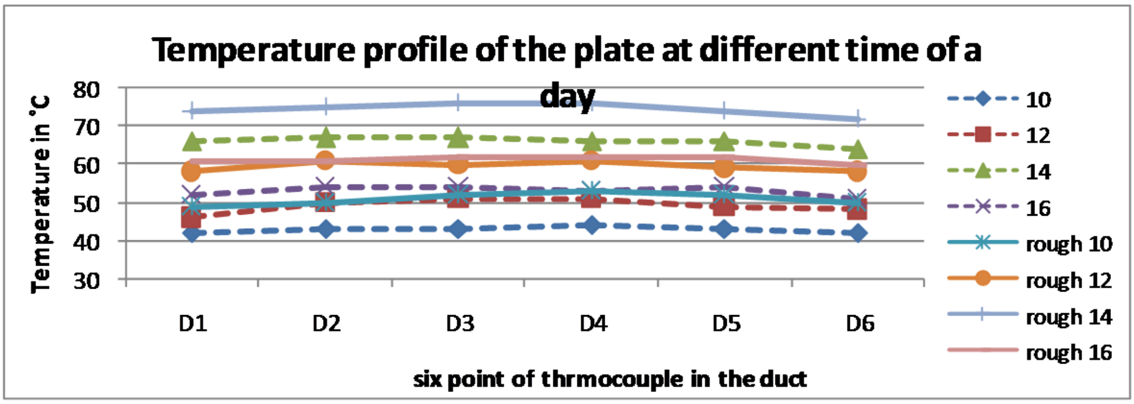

Figure 9

CONCLUSIONS

From the above results of the test conducted it can be concluded-

- The efficiency of the artificially roughened plate is higher in comparison to plane plate. This is due to higher turbulence caused by the artificial roughness.
- The graph between time and efficiency shows that the efficiency increases up to 2PM and afterwards decreases. This is due to the fact that the difference between the atmospheric temperature and average temperature decreases.
- The efficiency gradually rises with solar intensity during the day, and reaches maximum between 1 to2PM.
- The variation in efficiency at different mass flow rate shows irregularity. This is due to losses/leakages in the equipment. Also it may take place due to entry of atmospheric air from the rear end.
- The difference in average temperature of plane and rough absorber plate is high; this is due to the artificial roughness attached as they also act as a heat reservoir. We may decrease the pitch of the rhombus. Then obstruction will be increased, which will increase heat transfer rate.
- Change the shape and size of obstacles from rhombus to other shape and size, like square, rectangle etc.
- Obstacle material may be change, which has high thermal conductivity.
- Air can be double- passed through upper surface of the plate, which will increase the temperature of the air received by the air heater.

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